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PLACER POTENTIAL OF THE NEWFOUNDLAND CONTINENTAL SHELF: A PRELIMINARY ASSESSMENT

Final Report

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EXECUTIVE SUMMARY

The success of offshore placer mining operations in other parts of the world and a recent upsurge in mining exploration in Newfoundland provided the impetus to study the offshore placer potential on the continental shelf around the island of Newfoundland. The project has been funded through the Mineral Development Agreement under the scientific authority of Dr. D. Proudfoot of the Provincial Department of Mines and Energy.

The objective of this study as provided in the work statement (see Appendix A) is "to conduct a regional assessment of the coastal and marine placer potential of Newfoundland". This was done by compiling and mapping data upon which the development of modern marine placers and the preservation of relict placers in the offshore depend. These data include:

1. coastal lode and placer mineral occurrences
2. onshore Quaternary geology
3. sea level history
4. onshore drainage patterns
5. nearshore sedimentology
6. coastal exposure
7. shelf gradient

This report describes how these criteria can be used in the assessment of the marine placer potential in terms of a source-conduit (transport corridor)-sink framework.

A classification scheme and set of sedimentation models developed by the authors for high latitude marine placer deposits (Emory-Moore and Solomon, in press; Appendix B) are used to assess placer potential. The placer minerals are subdivided into medium-density heavy minerals (specific gravity from 4.2 to 6.0) and high-density heavy minerals (specific gravity from 6.0 to 21.0). Marine placer deposits are subdivided in this report on the basis of their environment of deposition and their present environment. Modern marine placer deposits are defined as those which are in equilibrium with the physical marine processes by which they are formed. Relict marine placer deposits are formed under conditions that differ from the marine setting in which they are found. Modern marine placer deposits can be classified according to the character of the mineral source, the marine sedimentary environment in which they form, and their mode of concentration. Relict deposits are classified on the basis of their primary depositional environment only and include submerged fluvial, glacigenic, and beach-nearshore deposits.

Three primary environmental factors control the processes of shelf sedimentation and consequently control the formation of modern marine placer deposits and the preservation potential of relict deposits. These factors are sea level variation, sediment supply, and the energy of the marine environment. The type of sediment supply and the magnitude of marine energy aid in the determination of the dominant fundamental concentrating mechanism (differential entrainment or entrapment). Sea level fluctuations and shelf gradient influence the size and preservation potential of placers formed and the efficacy of the enrichment processes. The variability of the Newfoundland continental shelf with

respect to the factors mentioned above was used to identify shelf areas that are likely to host specific placer deposit types. Twelve zones with unique combinations of formative factors were identified and evaluated.

It was found that Zones 3, 4, and 9 offer the best medium-density heavy mineral placer potential. Prospective commodities are, in Zone 3, chromite, in Zone 4, chromite and magnetite, and in Zone 9, chromite, zircon, and monazite. The best zones for high-density minerals are 3, 4, 5, 8, 9, and 10. Commodities of interest are, in Zones 3 and 4, platinum group elements, in Zones 5, 8, and 9, gold, tungsten, and tin, and in Zone 10, gold. Relict deposits are most likely to be found in Zones 5, 6, 7, 8, and 11, with the greatest abundance of heavy minerals occurring in the source rocks of Zones 5 and 11.

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1.0 Introduction

A successful offshore gold placer mining operation on the Alaskan continental shelf has provoked interest in the viability of seabed mining in Canadian waters (e.g., Samson, 1984; Hopkins, 1985). West Gold Incorporated is actively mining the Alaskan deposits at a rate of 30,000 ounces per year with a cash operating cost of less than US$200 per ounce. The total recoverable reserves for the deposit are estimated at 780,000 ounces (Mining Journal, 1986). Tin placers off the Soviet Union and Malaysia have also been the focus of extensive mining activity (e.g., Maslov, 1975; Ringis, 1976; Kudrass and Schulter, 1976), while other notable exploration activities include chromite prospects off Oregon (e.g. Kulm, 1988; Petersen et al., 1986; Petersen et al., 1987) and gold prospects offshore of New Zealand (Boyle, 1979) and British Columbia (Samson, 1984).

Newfoundland has recently experienced a significant growth in mineral exploration (Government of Newfoundland, 1988). Clearly, where mineralized bedrock and associated overburden sediment are located in proximity to coastal waters, a potential for marine placer deposits exists. This report presents a regional assessment of the marine placer potential of the continental shelf off Newfoundland and represents a continuation of earlier work (Emory-Moore and Solomon, 1989), which focused on gold potential alone, to include both the potential for high-density heavy minerals (specific gravity of 6.0 to 21.0; e.g., gold, cassiterite, and platinum) and medium-density heavy minerals (specific gravity of 4.2 to 6.0; e.g., chromite, zircon, and titaniferous magnetite). A classification scheme and set of depositional models developed for high latitude marine placer deposits (Emory-Moore and Solomon, in press; Appendix B) are used in this report to infer regional variations in marine placer potential and thus identify sites which may merit further investigation.

2.0 Deposit Classification

Marine placers are subdivided in this report on the basis of their environment of deposition and their present environment. Modern placer deposits are defined as those which are in equilibrium with the marine processes by which they are formed (e.g. modern beach placers). Relict marine placer deposits are formed under environmental conditions that differ from the marine setting in which they are found (e.g., submerged fluvial deposits).

Modern marine placer deposits can be classified according to the character of the mineral source, the marine sedimentary environment in which they form, and their mode of concentration (Emory-Moore and Solomon, submitted; Table 1).

(1) source: placer deposits that are sourced directly by the products of post-glacial weathering of bedrock are termed 'primary'. Deposits that are derived from the reworking of overburden sediment (e.g., glacigenic sediment) are termed 'secondary'.

(2) sedimentary environment: the modern shelf environment is divided into the beach-nearshore zone and the offshore zone. The beach-nearshore zone is defined as that area shoreward of the breaker zone and extending to the backshore beach complex. The offshore zone extends

seaward of the breaker zone to a depth of 100 m, which is an speculative limit of economically feasible dredging (Packer, 1987).

(3) mode of concentration: placer deposits in general can be divided into allochthonous and autochthonous varieties depending upon the distance travelled from the mineral source (Kartashov, 1971). Allochthonous deposits can occur hundreds of kilometres from their source and generally form discrete lenticular laminae interbedded with well sorted quartzose sands. They form under conditions of net sediment aggradation through a process of hydraulic sorting. Allochthonous placer minerals include zircon, monazite, ilmenite, rutile, magnetite, chromite, and fine-grained (i.e., generally < 50 microns) gold and platinum. Autochthonous deposits form close to their source, through grain entrapment, within porous gravel sequences and/or in bedrock crevices. They are residual in nature and occur in areas where the rate of marine erosion exceeds the rate of net sediment accumulation. Autochthonous placer minerals consist of the high-density heavy minerals and include cassiterite, coarse-grained gold, and platinum (Emery and Noakes, 1968).

Relict deposits are classified on the basis of their primary depositional environment only and include submerged fluvial, glacigenic, and beach-nearshore deposits.

3.0 Shelf Sedimentation and Marine Placer Formation

Three primary factors control the processes of shelf sedimentation and consequently control the formation of modern marine placer deposits and the preservation potential of relict deposits. These factors are sea level variation, sediment supply, and the energy of the marine environment (Davis and Clifton, 1987). An examination of the role that each of these factors plays in placer formation and a brief summary of the relevant data for the Newfoundland shelf are provided below.

3.1 Sea Level

Relative sea level movements (net results of eustatic and isostatic changes) affect the location and extent of mineral concentrations by changing the zone of sediment reworking by waves (e.g. Peterson et al., 1987). Relative sea level fluctuations also influence both the type and volume of sediment supplied to the shelf region.

For example, sea level regression results in base level lowering and erosion of previously deposited sediment by downcutting rivers. In this case, at river mouths, large volumes of sediment are supplied to the nearshore and offshore zones. Heavy minerals in the sediment supplied to the marine environment may be concentrated in barrier beaches and offshore shoals. Depending on the rate of aggradation and regression, placer deposits may be eroded and redeposited with the receding coastline or left behind to form relict beach ridges (e.g. Northeast Graham Island, B.C. - Samson, 1984). Transgression causes erosion of coastal bluffs and shoreward migration of the beach-ridge/nearshore complex.

The rate of sea level change also governs the degree to which sediment is reworked (e.g. Kudrass, 1984) and thus the likelihood of modern placer formation and relict placer preservation. Where sea level change is slow, sediment is extensively reworked and the probability of authochthonous placer formation should increase with the degree of reworking. A rapid sea level rise favors the preservation of relict placers as sediment reworking and re-distribution are minimal (Davis and Clifton, 1987).

A moderately rapid Holocene sea level rise on the East Australian Shelf (about 2.0 to 2.5 m/100 years) has concentrated heavy minerals on modern beaches and depleted residual shelf sediments (Kudrass, 1984; Jones, 1977). This suggests that previously formed allochthonous placers are destroyed and progressively reconcentrated as sea level rises. It is possible that in less energetic environments, the heavy minerals would be left behind as a lag as the rising sea level carries the silica-rich gangue landward (cf. Kudrass, 1987).

The postglacial sea level history of the Newfoundland shelf is poorly defined in most areas (Map 1). Sea level curves have been reported for the Northern Peninsula (Grant, 1972), western Newfoundland (Grant, in press) and southwestern Newfoundland (Brookes et al., 1985). Postglacial sea level changes along western Newfoundland vary from dominantly regressive in the north to a combination of regressive and transgressive in the south. Most rapid rates are about 3 m/100 years. Work on the Grand Banks indicates a post-glacial transgression of about 120 m (Fader and Miller, 1986) at an average rate of about 0.75 m/100 years. Recent work in northeastern Newfoundland indicates slow regression followed by slow transgression (Shaw and Forbes, 1988).

3.2 Sediment Supply

There are four primary sources of sediment and associated heavy minerals that supply the offshore. These are (1) modern fluvial discharge, (2) erosion of unconsolidated coastal bluffs, (3) erosion of coastal and submarine bedrock, and (4) submarine erosion and shoreward transport of unconsolidated sediment. Autochthonous placer deposits form under erosive conditions, where the sediment supply is low, whereas allochthonous placers require a moderate to high sediment throughput (see section 2.0, Deposit Classification). Relict placers have less potential where the modern overburden sediment is thick; therefore a low present-day sediment supply is favoured.

A significant portion (about 70%) of coastal Newfoundland is characterized by exposed bedrock and narrow continental shelves (Map 2) and the coastline is generally sediment-starved (Forbes, 1984). Sediment supply is abundant in areas where unconsolidated sediment is widely distributed along the coast or in the drainage area (e.g., St. George's Bay; Forbes, 1984) or where fluvial discharge is significant. The extent of unconsolidated submarine deposits is poorly known on the Newfoundland shelf for the most part. Since this study is a preliminary attempt to estimate marine placer potential it is assumed that offshore sediment sources are present, however they are accorded a low weighting factor in the assessment (Section 4.0). Net accumulation is not considered in this regional study as it is highly localized and not easily measured; it is however an important factor to address in detailed studies.

3.3 Marine Energy

Known high-latitude marine placers form preferentially in areas where exposure to oceanic waves is high (e.g. the Bering Sea and off the Oregon Coast). In general, autochthonous placers require high exposure to oceanic waves for both the erosion of source rock and the erosion and selective removal of light mineral sands (e.g. Nelson and Hopkins, 1972). Allochthonous placers form in areas of moderate to high coastal exposure where sediment is actively reworked and contemporaneously aggraded (e.g. Samson, 1984). In both cases variations in bathymetry and shoreline morphology ultimately control the location of marine placers. Preservation of relict placers is favoured by moderate exposures where sediment redistribution is minimal and aggradation is limited. As high latitude coasts are generally storm-dominated, relative marine energies can be approximated by evaluating the degree of coastal exposure and/or the shelf gradient.

In the case of the Newfoundland coastline, the highly irregular coastal morphology precludes the identification of meaningful regional patterns in exposure on the scale of this study. However, the gradient of the Newfoundland shelf varies in such a manner that regional patterns are evident (Map 3).

The gradient of the shelf influences the wave energy and also determines the spatial extent of the zone of offshore placer enrichment. For any specific set of environmental factors the hydraulic conditions necessary for the concentration of heavy minerals will fall within a critical water depth range. On a shallow gradient shelf, this zone will be larger and thus more economically promising than on a narrow shelf (e.g., the gold deposits of the Bering Sea, Alaska). All other factors being equal, the higher wave energies generated over a steep shelf will favour the formation of autochthonous beach-nearshore placers.

3.4 Summary

Table 1 illustrates the role of the above factors in the formation of individual deposit types. Heavy mineral sources are discussed in the following sections. 'Source type' and 'marine energy' aid in the determination of the dominant fundamental concentrating mechanism (differential entrainment or entrapment). Sea level fluctuations and shelf gradient influence the size and preservation potential of placers formed and the efficacy of the enrichment processes.

4.0 Assessment Procedure

The classification scheme and formation factors described above were used to assess the regional modern marine placer potential of the Newfoundland shelf. Shelf areas that are likely to host specific placer types are identified using the following procedure:

(1) establish regional trends in sea level movement, shelf gradient, and the distribution of sediment (Maps 1, 2, and 3),

(2) constrain the geographical zonation of the shelf using the previously discussed factors (i.e., sea level movement, sediment supply, and shelf

gradient) (Map 4); where one factor changes with respect to the other two, a new zone is created. In this manner, twelve zones are established, all of which have discrete combinations of control factors (Table 2),

(3) compare the factors present in each zone on the Newfoundland shelf (Table 2) with those identified for individual deposit types (Table 1). The likelihood of occurrence of each deposit type is determined by allocating points which reflect the degree to which the conditions prevailing in the zone correspond to the factors required by each deposit type. The relative potential for the occurrence of each deposit type within each zone is determined by totalling the number of points. In order to account for the fact that most zones contain more than one sediment supply source, 3 points are allotted if the most abundant sediment type in a zone matches the requirement for a given deposit type. Two are allotted if a less abundant sediment supply type in a zone matches the requirement for a deposit type, and 1 is allotted if the presence of a sediment source is assumed (i.e. offshore sources). For example, the factors determined for Zone 9, are: a relatively slow early regression followed by slow transgression, a shallow gradient shelf, and with the most prevalent sediment supplies emanating from coastal bluffs. Deposit type #4 (secondary offshore autochthonous deposits) requires a slow transgression (2 points), a shallow gradient shelf (1 point), sediment supplied from the offshore (this is a supply of unknown distribution, therefore only 1 point is allocated) (table 2). Thus the rating for deposit type #4 in Zone 9 is four. Deposit type #5 requires the same sea level and gradient factors as deposit type #4 with the most abundant sediment supply from coastal bluffs. Deposit type #5 rates six in Zone 9. This is determined by allotting 1 point for each of sea level movement and rate of change, as well as shelf gradient, and allotting 3 points for the sediment supply (the principal source of sediment in Zone 9 matches that required for the deposit type in question). Table 3 provides a listing of the deposit types and a ranking of their relative potential for occurrence within each zone.

(4) the zones where primary mineralization occurs in proximity to the Newfoundland coast are identified (Map 5 - medium-density minerals, Map 6 - high-density minerals).

4.1 Limitations

The assessment scheme described above is restricted to simplified formation conditions and is not amenable to the evaluation of pre-Late Wisconsinan events and their possible role in placer formation. Multiple glaciations may have served to alternately concentrate and disperse placers of all types, creating locally enriched glacigenic deposits (e.g., Westland, New Zealand; Henley and Adams, 1979). This behaviour is analogous to fluvial placer formation where multiple rejuvenation and down-cutting events create increasingly rich deposits (Sutherland, 1985). A further restriction of the assessment scheme is the use of relative indicators (i.e., a 'high' rate of sea level fluctuation versus a 'low' rate). This is necessary because the effects of the controlling factors are not quantified. However, the assessment scheme does provide a geologic framework and rationale for the assessment of regional marine placer potential.

5.0 Assessment of Medium-Density Mineral Marine Placer Potential

Medium-density minerals have specific gravities in the range 4.2 to 6.0. They are typically very fine grained (<0.3 mm), and are mechanically and chemically stable. Their stability and fine size permit transport tens or hundreds of kilometers from source.

The medium-density minerals considered in this study include chromite (chromium), which is associated with peridotites, dunites, and gabbros; ilmenite and magnetite (titanium), which are associated with anorthosites; and zircon (zirconium) and monazite (thorium), which are associated with granitic rocks. For the purpose of this study, the medium-density heavy minerals are assumed to occur in accessory amounts in all potential source rocks.

5.1 Distribution of Medium-Density Mineral Sources

There are two basic sources of the sediment and associated heavy minerals which are supplied to the coastal and nearshore regions. Primary sources consist of coastal and submarine bedrock outcrops currently being weathered and eroded. Secondary sources include modern fluvial systems, unconsolidated coastal bluffs, and submarine sediments. These sources are described below, with consideration given to the spatial distribution of medium-density source rocks and unconsolidated materials, and to the potential for localized fluvial discharge of medium-density minerals. The coastal zonation described in Section 4.0 provides the geographic framework for discussions of the spatial distribution of heavy mineral potential.

5.1.1 Primary Sources

The disseminated nature of medium-density minerals in their source rocks and the slow process and high energy requirements of bedrock erosion suggest that primary deposit types will not host economic quantities of medium-density minerals. However, the distribution of primary source rocks is important in evaluating the medium-density mineral content of the secondary sources (see Map 5). Granites are clearly the most widespread primary source, with a total surface area in excess of 15,000 km^2. Zone 5 has the most extensive coastal exposure of granite, measuring approximately 150 km. Roughly 80 km of the coastline in zone 9 is formed in granitic rock; coastal exposures of granite are otherwise very limited (Map 5; Appendix C).

The only significant outcrop of anorthosite, an ilmenite and magnetite source, is situated adjacent to the head of St. George's Bay (Zone 4). It measures approximately 300 km^2 and has no coastal exposure.

Ophiolitic sources of chromite are found primarily along the west coast (zones 3 and 4), north and south of the Bay of Islands. Other exposures occur in the southwestern, central, and eastern (Gander River basin) portions of the island; and there are notable outcrops of ultramafic peridotites and dunites immediately north of Hare Bay on the Great Northern Peninsula (Zone 1). The total surface area of potential chromite source rocks does not exceed 1000 km^2, and there is limited coastal exposure. However, placer source potential of some

ophiolite bodies is improved by their proximity to the coast and to fluvial conduits.

5.1.2 Secondary Sources

There is a nearly continuous veneer of glacial drift in the interior of insular Newfoundland (Map 2; Appendix C). In contrast, most of the coast consists of exposed bedrock. Glaciomarine deposits exposed as a result of post-glacial sea level regression are found along the coast adjacent to Zone 1. The deposits may contain medium-density minerals derived from granite outcrops situated approximately 15 km inland.

Glacigenic deposits of varying thickness extend to the coast adjacent to Zone 2, providing a significant secondary source for nearshore sediments. The deposits partially cover a large granitic outcrop which is assumed to have yielded particulate zircon and monazite. Drift along the coast adjacent to Zone 3 is less extensive and discontinuous, reflecting the influence of the more variable topography. Unconsolidated bluffs likely contain chromite yielded by the ophiolitic source rocks.

The coastal region adjacent to Zone 4 bears a substantial cover of glacial drift and modern fluvial deposits. These unconsolidated sediments contain concentrations of particulate ilmenite and magnetite (e.g. Black Sand Provincial Park), probably transported from the Steel Mountain anorthosite body east of St. George's Bay by glacial and post-glacial processes. There is a discontinuous cover of drift overlying granites and ophiolitic gabbros along the western-most portion of the coast in Zone 5. East of Port Aux Basques, the sediment cover is negligible (Map 2; Appendix C).

A large proportion of the coast adjacent to Zone 9 bears a continuous cover of unconsolidated glacial drift (Map 2; Appendix C). Associated source rocks include coastal and inland granites, and less extensive (<100 km^2) inland outcrops of ophiolites. Based on mineral source availability, zone 9 is prospective for zircon, monazite, and to a lesser degree, chromite (Maps 2 and 5; Appendix C).

The coastal region adjacent to Zone 8 has a limited, discontinuous cover of glacigenic sediments. The availability of medium-density heavy minerals to Zone 8 depends largely upon the provenance of the drift, and on the efficiency of post-glacial fluvial activity.

The capacity of fluvial discharge to provide sufficient volumes of medium-density minerals for the generation of nearshore marine placers has been demonstrated. For instance, the Fox Island River has been identified as a conduit for placer chromite derived from the Lewis Hills ophiolites on the West coast of Newfoundland (Zone 4) (Emory-Moore et al., 1988). The relative contribution of modern fluvial discharge as a placer mineral source cannot be thoroughly assessed without more detailed investigation. However, a few observations can be made based on the information presented in Map 7, which shows the major river networks and the contemporary drainage areas contributing to each zone.

Streams draining the inland region adjacent to Zone 4 may convey particulate ilmenite and magnetite yielded by the anorthosite outcrop. The proximity of ophiolites and associated tills to the Gander River in the northeast suggest that the river is a possible conduit for chromite-bearing sediments. Another potential fluvial source is the Little Codroy River in southwestern Newfoundland, which drains a region occupied by granites, ophiolitic gabbros, and associated drift (zone 5) (Maps 2, 5, and 7; Appendix C).

The offshore area adjacent to Zone 12 in the Strait of Belle Isle is known to include a variety of unconsolidated materials ranging from sandy silts to boulder lags (Woodworth-Lynas et al., in press). The onshore areas on the Labrador side are comprised in part of iron-bearing sediments which may contain magnetite and ilmenite. On the Newfoundland shore, ophiolitic rocks of the Hare Bay Allochthon may contribute chromite to Zone 12 (Map 5).

5.2 Medium-Density Mineral Placer Potential

In Zones 5, 7, 8, and 11 the autochthonous deposit types (types #1, #2, and #3) are ranked higher than other types (table 3). The low density contrast between medium-density heavies and their light mineral counterparts all but precludes the development of substantial autochthonous medium-density placer deposits. This generalization is particularly valid in the case of resistant primary (bedrock) sources which yield low volumes of sediment, such as the extensive granitic coast adjacent to Zone 5. These zones therefore show little medium-density placer potential.

Zones 3, 4, and 9 offer the highest medium-density placer potential, as they have significant secondary (unconsolidated) sources (Map 2) and favourable depositional environments. Placer deposit types associated with each of these zones include type # 2 (primary autochthonous offshore), type # 4 (secondary autochthonous offshore), type # 5 (secondary allochthonous beach and nearshore), and type # 6 (secondary allochthonous offshore). The characteristics of each zone are discussed independently below, with emphasis on their medium-density allochthonous placer potential.

Coastal Zone 3 extends from St. Paul's Inlet to the shore adjacent to the Lewis Hills on the west coast. The drainage area contributing to Zone 3 includes both Grand Lake and Deer Lake. Large exposures of granite occur inland along the drainage divide, but the sources of primary interest are the ophiolites and associated discontinuous glacigenic deposits found along the coast (Maps 2 and 5; Appendix C). There is potential for wave erosion of unconsolidated drift as well as discharge of chromite-bearing sediments from the numerous streams draining areas underlain by ophiolitic peridotites, dunites, and gabbros (e.g. Serpentine River). The recent sea level transgression and relatively low shelf gradient suggest substantial reworking of sediments derived from fluvial sources and erosion of unconsolidated drift. In short, Zone 3 has the potential to host secondary allochthonous chromitiferous placers.

Zone 4 extends southward from Zone 3 to the coast adjacent to the Anguille Mountains. The drainage area contributing to Zone 4 has a maximum relief of 670 m. Medium-density mineral source rocks within the contributing area include the Lewis Hills ophiolite north of Port au Port Bay, and the 300 km^2 anorthosite

exposure east of St. George's Bay. Numerous rivers draining the region are potential conduits for particulate titaniferous magnetite derived from anorthosites and associated glacial drift. Heavy mineral concentrations can be seen along the beaches of St. George's Bay (at Black Sands Provincial Park) and are known to occur on Flat Bay Island (D. Forbes, pers. comm., 1989). As noted previously, Fox Island River is a conduit for chromite found in high concentrations in the nearshore environment of Port au Port Bay. The recent sea level transgression and shallow shelf gradient of Zone 4 suggest substantial reworking of the abundant source material.

Zone 9, like Zone 4, has a high potential for allochthonous deposit types (#'s 5 and 6). Bedrock source materials are dominated by granites, with secondary ophiolitic materials. The widespread unconsolidated sediment cover likely contains monazite and thorium derived from the granites and chromite from the ophiolites. The available evidence suggests that sea-level changes have been small and slow which would allow reworking of the secondary source materials.

6.0 Discussion of High-Density Mineral Marine Placer Potential

Autochthonous placer mineral deposits are, by definition, restricted to relatively coarse-grained high-density minerals (e.g. gold, platinum, cassiterite, and scheelite). Autochthonous placer minerals form by grain entrapment in porous gravels and therefore must be both dense enough and large enough to resist transport in environments that are too energetic for the deposition of sand-sized silicate materials. In this sense, fine-grained (silt-sized and smaller) high-density minerals will likely behave in a manner similar to the medium-density minerals and thus form allochthonous placers. This is illustrated by the fine-grained gold beach placers found in the Queen Charlotte Islands, B.C. (Samson, 1984), platinum placers found in Chagvan Bay, Alaska (Owen and Moore, 1976), and fine cassiterite and gold deposits of the Chaun Gulf, East Siberian Sea (Maslov, 1975).

6.1 Distribution of High-Density Mineral Sources

6.1.1 Primary Sources

Of the twelve zones identified on the Newfoundland shelf, five are associated with onshore primary gold mineralization (Zones 5, 8, 9, 10, and 11) (Map 6; Appendix C). Potential sources of platinum are restricted to trace amounts of very fine grained PGE's found in ophiolitic rocks in the Lewis Hills (Page and Talkington, 1984) (Zone 3). Cassiterite is found in the Ackley Granite along the south coast (Zone 5). An isolated scheelite (tungsten) deposit occurs along the coast of Gander Bay (Zone 9).

6.1.2 Secondary Sources

Glacial drift acts as an intermediate collector of high-density minerals which accumulate in tills and other glacial deposits eroded from mineral-bearing bedrock. The use of till geochemistry and panning as a means of prospecting for lode deposits is well known. In some cases the tills themselves may attain economic value, but, in general, they disperse minerals of interest. Thus, glacial drift can provide vast amounts of dilute, easily eroded source material

to concentrating mechanisms in the marine environment. Only in Zones 2, 3, 4, and 9 are appreciable amounts of drift found adjacent to the coast (Map 2: Appendix C).

The Lewis Hills Ophiolite in Zone 4 is known to contain trace amounts of finely disseminated PGE's (Page and Talkington, 1984) The unconsolidated glacial and fluvial deposits which are found adjacent to the offshore in that area are therefore considered to be potential sources of PGE's. Gold and scheelite occur in the bedrock within the Gander Bay drainage (Map 6; Appendix C), up-ice (Late Wisconsinan) from the present coast. Glacial drift and, to a lesser extent, post-glacial fluvial deposits may therefore act as a source of high-density minerals to the modern offshore.

As noted previously, the extent and nature of unconsolidated sediments in the Newfoundland offshore is largely unknown. While it is possible to determine which coastal regions are less likely to host placer deposits on the basis of their depositional environments, no offshore area adjacent to a significant high-density mineral source can be dismissed as a potential placer site without knowledge of the offshore surficial geology. For example, it may be that ice moving off of the Baie Verte Peninsula (Zones 10 and 11) deposited auriferous tills on the presently submerged shelf area. If present, such deposits may provide source material for the formation of secondary autochthonous placers.

6.2 High-density Mineral Marine Placer Potential

Although primary placer deposits (deposit type #1 and #2) are considered to be the least economically attractive deposit type (see below), they are easily mined with minimal operating costs. Areas in Zones 8, 9, 10 and 11, in which gold-bearing bedrock is subject to wave erosion, hold a considerable potential for this deposit type, particularly for local prospectors. The gold within the mineralized bedrock of Zone 5 is fine-grained (McKensie, 1986) and thus the placer deposits are restricted to allochthonous types. Tin- and tungsten-bearing minerals occur in the primary source rocks along the coasts of Zone 5. A tungsten-bearing deposit is found along the coast in Zone 9. These zones hold some potential for generating primary autochthonous placer deposits. However, the price for these commodities will likely make any placer deposits uneconomical in the short term.

Allochthonous beach deposits (deposit type #5) may occur in Zones 3 and 4 (PGE's), 5, 8, 9, 10, and to a lesser extent 11 (gold and/or cassiterite). Because the assumed source of sediment in Zone 10 is offshore and because the sea level transgression was limited, the potential for allochthonous deposits is less than in the other zones. In all areas the formation of allochthonous beach deposits requires a high volume of sediment supply and will be localized.

Offshore allochthonous deposits (deposit type #6) may be found in Zones 3 and 4 (PGE's) and in Zones 5, 8, 9, 10, and to a lesser extent 11 (gold and/or cassiterite). The rapid post-glacial regression which occurred in Zone 11 may increase the potential for this type of deposit by generating large volumes of sediment at the mouths of some rivers (e.g., at the head of White Bay).

7.0 Relict Placers

Areas characterized by a strong transgressive sea level are the most ideally suited for the preservation of relict placer deposits. In this respect, Zones 6 and 7 hold the greatest potential on the Newfoundland shelf, but of the two, only in Zone 7 is there notable mineralization on-land. Zones 5 and 11 show some potential for relict placer preservation (Table 3), and have more occurrences of gold and other heavy minerals (Maps 5 and 6). Zone 8 is similarly ranked, but has less heavy mineral potential.

8.0 Relative Economic Importance of the Marine Placer Deposit Types

Given the wide range of deposit types that may occur on the Newfoundland shelf (see Table 3), it is important to establish which deposit types hold the greatest economic promise. In this regard, the following generalizations are made:

(1) 'primary' placer deposits (types #1 and #2) are restricted to the high-density minerals. They are limited by the effectiveness of postglacial weathering and the extent of exposed mineralized bedrock. As such, they are generally low volume although locally high grade (e.g., the beach placers of the Ovens district, Nova Scotia, and Shuttle Island, B.C.; Samson, 1984),

(2) secondary allochthonous placer deposits (types #5 and #6) are of interest for medium-density minerals. They may attain sufficient grade and tonnage for high-density minerals, but the particulate size will likely be too fine-grained for separation using standard gravity techniques,

(3) secondary autochthonous placer deposits (types #3 and #4) are neither restricted by a low availability of source material nor the grain size of the high-density minerals. In areas of primary mineralization, glaciation has resulted in the provision of ample low-grade auriferous material. When subject to marine processes, the extent of the deposit is limited to the critical zone of sediment reworking. During periods of sea level transgression the zone of reworking can attain substantial breadth (e.g., gold placers offshore Alaska; Nelson and Hopkins, 1972).

9.0 Summary of Conclusions

Map 8 summarizes the relative potential for each placer deposit type and the distribution of source rocks by zone. The following points are illustrated:

1. Zones 3, 4, and 9 offer the highest medium-density mineral placer potential. Prospective commodities are, in Zone 3, chromite, in Zone 4, chromite and magnetite, and in Zone 9, chromite, zircon, and monazite.

2. The most prospective zones for high-density minerals are 3, 4, 5, 9, and

10. Commodities of interest are, in Zones 3 and 4, platinum group elements, in Zones 5 and 9, gold, tungsten and tin, and in Zone 10, gold.

9. Relict deposits are most likely to be found in Zones 5, 6, 7, 8, and 11. Of these, zones 5 and 11 show the highest heavy mineral potential (Zone 5: gold, tungsten, tin; Zone 11: gold, chromite).

10.0 Recommendations

This initial study has identified zones which are most likely to host modern and relict marine placers on the continental shelf of the island portion of Newfoundland. It is recommended that the most prospective areas, specifically the northeast and southwest coasts, be investigated in greater detail. Sediment samples and geophysical data from surveys conducted by the GSC off the southwest coast in August, 1988 (Forbes and Shaw, 1989) can be used to characterize offshore sediments and identify heavy mineral anomalies. These data can be incorporated into a geographical information system (GIS) and used in association with morphometric and oceanographic data to infer areas of probable marine placer development, based on genetic model principles. If warranted, subsequent field surveys could be conducted to delineate placer deposits and further refine the marine placer deposit models. These studies should be supplemented by investigations of relict marine placers onland to investigate in more detail the stratigraphy and geometry of placer concentrations in the marine environment.

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Table 1. Deposit classification and assessment factors for high latitude marine placer deposits (cross-hatching indicates preferred choice; from Emory-Moore and Solomon, submitted (Appendix B)).

DEPOSIT CLASSIFICATION					CONSTRAINING FACTORS IN THE ASSESSMENT OF HIGH LATITUDE MODERN MARINE PLACERS													
					Sea Level					Marine Energy				Sediment Supply				
					Movement			Rate		Exposure		Shelf Gradient		Source Type				Net Accumulation
					trans.	stable	regress	fast	slow	high	mod.	steep	shallow	bedrock	offshore	Coastal bluffs	fluvial	high	low
MODERN	Primary Source	beach / nearshore	Autochthonous	1	▨				▨	▨		▨		▨					▨
		offshore		2	▨	▨			▨	▨			▨	▨					▨
	Secondary Source	beach / nearshore	Autochthonous	3	▨				▨	▨		▨				▨			▨
		offshore		4	▨				▨	▨			▨		▨				▨
		beach / nearshore	Allochthonous	5	▨	▨	▨*		▨	▨	▨		▨		▨	▨	▨	▨	
		offshore		6		▨	▨		▨		▨		▨		▨		▨	▨	
CONSTRAINING FACTORS IN THE PRESERVATION POTENTIAL OF RELICT PLACER DEPOSITS																			
RELICT	fluvial			7	▨			▨			▨		▨						▨
	glacigenic			8	▨			▨			▨	▨							▨
	beach / nearshore			9	▨			▨			▨	▨							▨

*where the source type is fluvial

Table 2. Factors used in the assessment of marine placer potential on the Newfoundland shelf.

ZONE	SEA LEVEL					WAVE ENERGY				SEDIMENT SUPPLY					
	Movement			Relative Rate		Exposure		Shelf Gradient		Source Type				Net Accumulation	
	transg.	stable	regress	fast	slow	high	mod.	steep	shallow	bedrock	offshore	bluffs	fluvial	high	low
1			X	X					X	(3)	(1)	(2)	(2)		
2			X	X					X	(2)	(1)	(3)	(2)		
3	X		X		X				X	(2)	(1)	(2)	(2)		
4	X		X		X				X	(2)	(2)	(3)	(2)		
5	X		X		X			X		(3)	(1)	(2)	(2)		
6	X			X					X	(2)	(1)	(2)	(2)		
7	X			X				X		(3)	(1)	(2)	(2)		
8	X		X		X			X		(3)	(1)	(2)	(2)		
9	X		X		X				X	(2)	(1)	(3)	(2)		
10	X		X		X				X	(3)	(1)	(2)	(2)		
11			X	X				X		(3)	(1)	(2)	(2)		
12			X	X					X	(2)	(2)	(2)			

SOURCE TYPE (1) More Abundant (2) Less Abundant (3) Unknown

TABLE 3

Ranking of Deposit Types by the Number of Factors in Each Zone

Modern Deposits

# of Points	Zones											
	1	2	3	4	5	6	7	8	9	10	11	12
6				5	1		2	1	5	2		
5			1 2 5 6	2 3 6	2 3		1	2 3	2 3 6	1 5		
4	5 6	5 6	3 4	1 4	5 6	5	3	5 6	1 4	3 4 6	1	2 5 6
3	2 3	1 2			4	1 2 3 4 6	5	4			2 3 5 6	1 4
2	1 4	3 4					4 6					3
1											4	

Relict Deposits

3						7	8 9					
2	7		7	7	8 9	8 9	7	8 9	7	7	8 9	7
1	8 9	7 8 9	8 9	8 9	7			7	8 9	8 9	7	8 9

Relative likelihood of occurrence for individual deposit types within the geographic zones on the Newfoundland shelf (based on the weighted assessment factors as described in Section 4.0).

APPENDIX A

C-CORE 1988 MDA WORK STATEMENT

Objectives

To conduct a regional assessment of the coastal and marine placer potential of Newfoundland.

Products

1. Two maps (1:500,000 scale) which demarcate zones of relative marine placer potential for the two classes of placer minerals; the light heavies (e.g. titanium and chromite) and the heavy heavies (e.g. gold and platinum).

2. A report which describes the criteria used in the assessment of the marine placer potential. The criteria are based on a source-conduit (transport corridor)-sink framework. A comparison with existing conceptual marine placer models will be made on the basis of coastal processes, sea level history, and rate of sediment supply. Marine placer potential will be evaluated on a regional scale and described in relative terms (e.g. low, medium, and high). Data to be complied in order to accomplish the stated objective include:

    1. coastal lode and placer mineral occurrences
    2. onshore Quaternary geology
    3. sealevel history
    4. onshore drainage patterns.
    5. nearshore sedimentology
    6. coastal exposure
    7. shelf gradient

Contract specifications

1. The contract cost is $15,000 and will cover data gathering and report production. The payment schedule will be $5000 on contract approval, $7000 on submission of an article to "Current Research", and the remainder ($3000) on contract completion.

2. Department of Mines will produce the maps in their cartography department. C-CORE will submit the maps for drafting no later than January 15, 1989.

3. The maps and report will be published as a Department of Mines "White Cover" report.

4. A progress report will be issued on September 15, 1988.

5. C-CORE agrees to submit an article to "Current Research" describing the work in progress.

6. The contract completion date is April 1, 1989.

APPENDIX B

SEDIMENTARY DEPOSIT MODELS FOR GOLD PLACER FORMATION ON HIGH LATITUDE SHELVES

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ABSTRACT

High latitude modern marine placer gold deposits are classified on the basis of three generic parameters: the source, the marine sedimentary environment and the mode of mineral enrichment. The classification scheme differentiates between primary and secondary sources, nearshore/beach and offshore environments, and allochthonous, autochthonous style of mineral enrichment. High latitude relict marine placer deposits are classified by their primary depositional environment only . Variation in sea level, marine energy and sediment supply are used to develop working deposit models for nine discrete deposit types. These simplified models are designed to help the placer explorationist in preliminary target ranking and discrimination. They are by no means exhaustive and are amenable to further refinement as more information becomes available.

keywords: marine placers, high latitude, classification, sedimentary models

1.0 INTRODUCTION

The commonly held principle that the effects of glaciation hinder the formation of placer deposits, although substantiated in the case of fluvial placers (e.g.,Sigov et al 1971), is not necessarily true of marine placer deposits. As an example, offshore placer gold mining on the Alaskan shelf has reached a production level of 30,000 ounces per year with a cash operating cost of less than US$200 per ounce; total reserves are estimated at 780,000 ounces (Mining Journal, 1986). Furthermore, on a global scale, the most notable marine placer gold occurrences exist in zones which have been previously glaciated (e.g., Alaska, USSR, New Zealand and Canada). It is important to appreciate that the effects of glaciation have in all cases enhanced the richness of these marine placer deposits through the provision of ample low grade auriferous drift which has subsequently been reworked by postglacial marine processes. Exploration for high latitude marine placer deposits is hampered however by a lack of deposit models on which to develop appropriate strategies; this is particularly true on high latitude shelves which are characterized by complex sea level history and variable glacial deposits.

The focus of this paper is the development of conceptual sedimentary models for marine placer gold formation on high latitude shelves. The models are designed to serve the placer explorationist as a first approximation of target sites. Rather than draw on complex hydrodynamic models, the use of simplified models which reflect the most characteristic

features of deposit genesis are applied.

2.0 CLASSIFICATION

For the purpose of this paper high latitude shelves are defined as shelf areas that were extensively and repeatedly glaciated during the Quaternary. Marine placer deposits which are formed by recent marine processes are termed 'modern' placers whereas deposits which form under environmental conditions that differ from the modern marine setting are termed 'relict' placers (e.g., submerged fluvial placers).

2.1 Modern Placer Deposits

A classification scheme for high latitude modern marine placer deposits is proposed based on three generic parameters: the character the source unit, the marine sedimentary environment in which a placer deposit forms and the mode of mineral concentration (Figure 1).

Placer deposits which are derived form the post-glacial weathering of bedrock are termed 'primary' while those derived from the reworking of overburden sediment (e.g., glacigenic sediment) are termed 'secondary'. The size and morphology of gold particles within the source unit dictate their hydraulic behaviour and consequent mode of concentration (see below).

The marine sedimentary environment is broadly divided into the

beach/nearshore zone and the offshore zone. The beach/nearshore zone is defined as that area shoreward of the breaker zone and extending to the backshore beach complex. The offshore zone extends seaward of the breaker zone to a water depth of approximately 80 meters which is considered to be the current practical dredging limit (Packer, 1987).

Finally, offshore gold placer deposits are divided into allochthonous and autochthonous varieties, depending on their mode of concentration (the terms allochthonous and autochthonous were originally introduced by Kartashov (1971) in his classification of alluvial placer deposits). Allochthonous deposits are characterized by fine-grained gold. The gold grains are often subject to multiple erosional/depositional episodes and, consequently, may occur up to hundreds of kilometers from source. These deposits form through selective hydraulic sorting (most commonly that of differential entrainment) where the particulate gold is commonly found associated with well sorted heavy mineral ('black') sands. It is the superimposition of multiple gold-rich layers which creates an economic deposit and thus the environmental setting must be one of net sediment aggradation.

Autochthonous placer deposits, restricted in the present context to coarse-grained gold, form close to source through grain entrapment within gravel interstices or bedrock crevices. Autochthonous deposits are residual in nature and occur in areas where the rate of marine reworking and sediment removal exceeds the rate of sediment accumulation.

2.2. Relict Placer Deposits

Relict deposits are classified by their primary depositional environment and include submerged fluvial, glacigenic and beach/nearshore deposits.

3.0 HIGH LATITUDE SHELF SEDIMENTATION AND MARINE PLACER FORMATION

Models of continental shelf sedimentation classically describe the character and interaction of sea level fluctuations, sediment supply and energy of the ocean (e.g., Davis and Clifton, 1987). An attempt is made here to qualitatively examine the role of these factors in the formation of different placer types on high latitude shelves. The results are presented in Figure 1.

3.1 Relative Sea Level

Glacio-isostatic, glacio-eustatic and tectonic events have caused large variations in the extent and rate of sea level change over high latitude shelves during and since the Late Wisconsin glaciation. For any given site, the vertical succession of offshore sediments reflects the lateral succession of environments that have migrated over the site; a general coarsening-upward sequence would therefore be observed under regressive conditions and conversely, a general fining-upward sequence under transgressive conditions. As the necessary hydraulic conditions for offshore placer formation fall within a critical water depth zone, sea level changes exercise a significant impact on their location and extent. Futhermore, variations in sea level affect the type and volume of sediment

supply to the marine environment (see below).

The rate of relative sea level change governs the degree to which sediment is reworked and thus the likelihood of placer formation. Where sea level change is slow, sediment is extensively reworked and the probability of allochthonous and autochthonous placer formation greatly increased. Conversely, in the case of relict deposits, a rapid sea level rise affords the highest preservation potential as sediment reworking and re-distribution is minimal.

3.2 Sediment Supply

There are four primary sources of sediment and associated particulate gold to the coastal and nearshore regions: modern fluvial discharge, erosion of unconsolidated coastal bluffs, submarine erosion and shoreward transport of unconsolidated sediment and erosion of coastal and submarine bedrock outcrops. Under transgressive conditions offshore sediment and unconsolidated coastal bluffs (where present) are volumetrically an important source of sediment supply. Under regressive conditions, fluvial discharge is an important, albeit localized, source of sediment. Bedrock outcrops, in most instances, are volumetrically the least significant source of sediment.

The rate of net sediment accumulation is similarly an important variable in placer formation. As previously discussed, autochthonous placer deposits form under erosive conditions where the sediment supply is low while allochthonous placers require a moderate to high sediment supply

(note: if the sediment supply is too high the depositional site will not be afforded the required time period for reworking and the resulting deposit will not be enriched with heavy minerals). Relict placers are less prospective where overburden sediment is thick; a low sediment supply is thus favored.

3.3 Marine Energy

Given that high latitude coasts are generally storm dominated, relative marine energies can be approximated by evaluating the degree of coastal exposure and to a lesser extent, the shelf gradient. Autochthonous placers form preferentially in areas with a high exposure to waves as required for both the erosion of source rock and the erosion and select removal of light mineral sands. Allochthonous placers form in areas of moderate exposure where sediment is actively reworked and contemporaneously aggraded. Preservation of relict placers is favored by moderate exposures where sediment redistribution is minimal.

The gradient of the shelf influences the wave energy and also determines the spatial extent of the zone of offshore placer enrichment. The hydraulic conditions necessary for the concentration of particulate gold generally falls within a critical water depth range which on a shallow gradient shelf will be larger and thus economically more prospective than that of a narrow shelf. This factor is less critical in the formation of autochthonous beach/nearshore placers where very high wave energies are required and the degree of sediment reworking is not a function of water depth.

4.0 SEDIMENTARY MODELS FOR GOLD PLACER DEVELOPMENT

Each deposit type in the classification system can form under a range of conditions constrained by sea level, sediment supply and marine energy. In the following sections both the formation parameters discussed above and, where possible, the character of known deposits are used to formulate "working" sedimentary models for each deposit type. Although it is recognized that marine placer deposits are generally polygenetic and thus compositionally complex, the models presented in this paper are restricted to simplified formation conditions. The models and associated formational indicators are however felt to provide a good geologic framework for initial target discrimination.

4.1 Modern Deposits

4.1.1 Primary Autochthonous

Type # 1: beach

Deposit type #1 forms through post glacial abrasion of mineralized bedrock at the beach/nearshore zone. The gold is generally found at the base of bedrock bluffs where it is concentrated within gravels or bedrock crevices (Figure 2). This type of deposit forms best under transgressive conditions where there is sustained erosion of the source rock.

Placers of this type are generally spatially and economically restricted as a result of limited exposure of mineralized bedrock. These deposits are however good targets for small-scale operators and are readily prospected. Beach deposits in the Ovens district of Nova Scotia were formed, at least in part, in this manner and were mined during the early nineteenth century with an estimated gold production of 2,000 ounces (Samson, 1984). Similar deposits occur on Shuttle Island, British Columbia and Wine Harbour, Nova Scotia (Samson, 1984).

Type # 2: Offshore

This type of deposit forms through wave erosion of mineralized bedrock exposed on the seabed(Figure 3). Once liberated, the gold remains close to source, caught within the porous framework of associated gravels or within natural bedrock riffles (e.g., bedding planes and vertical joints). This deposit type is favored by a stable or slow moving sea level where the exposed bedrock is subject to a prolonged period of wave abrasion.

On high latitude shelf areas, the Late Wisconsinan sea level has fluctuated considerably and thus the time available for wave abrasion at any specific location has been relatively short. This constraint aside, the richness of type # 2 placers is dependant on the surficial exposure of mineralized bedrock which, in most instances, is limited and is likely insufficient for the development of an economic placer deposit. Although this deposit class is not considered a high priority target, it can provide indications of proximal lode mineralization within subseabed

bedrock suites.

An occurrence of placer gold offshore Country Harbour, Nova Scotia has been interpreted by some investigators to be of this origin (Anonymous, 1968).

4.1.2 Secondary Autochthonous

Type # 3: Beach

Beach deposits of this class form through the erosion of unconsolidated coastal bluffs (Figure 4). The gold is concentrated at the foot of the bluffs in basal units of sand or more frequently gravel. Deposits of this type are less likely to form under regressive conditions where coastal bluffs generally occur beyond the zone of active wave erosion.

The erosion of unconsolidated bluffs is both more effective and more extensive than that of bedrock and as a result type #3 deposits are a more attractive prospect than type #1. Several small occurrences of this deposit class have been identified along the coast of Canada, the most notable include Wreck Bay, western Vancouver Island and Issacs Harbour, Nova Scotia (Samson, 1984). The beach deposits along the coast of Nome, Alaska (Nelson and Hopkins, 1972) and northeastern Graham Island, B.C. (Samson, 1984) are, in part, the product of the same process.

Type # 4: Offshore

These deposits form through submarine reworking of auriferous glacial drift during a sea level transgression (Figure 5). Glacial facies which most commonly host particulate gold are morainal sequences (where mutual attrition of particles is high and thus gold is most frequently in a free state) and glacial outwash where the gold may have undergone one phase of hydraulic concentration (Trofimov, 1964). Downcutting of glacigenic sediment by marine reworking may result in the concentration of particulate gold, particulary within basal gravels located at the interface of an impervious substrate (e.g., the reworked/unreworked sediment boundary; bedrock). The downcutting of glacial sediment during interglacial times is also responsible for the formation of very rich fluvial deposits in British Columbia (Eyles and Kocsis, 1988); deposit type # 4 is the marine analogy.

These deposits are of particular relevance because they can achieve considerable size, limited by the areal extent of auriferous drift within the zone of active wave reworking. The placer gold deposits of offshore Nome, Alaska are, at least partially, of this variety and serve to illustrate their potential economic importance (Nelson and Hopkins, 1974). Complete "unmixing" of glacial drift during the Holocene transgression has been reported in several localities on the Canadian shelf (e.g., Conception Bay, Newfoundland; Slatt, 1974: the Scotian Shelf; Piper et al., 1984) and suggests that the formative mechanism for type #4 gold placers is prevalent. Anomalous concentrations of gold offshore Country Harbour and Ovens, Nova Scotia are interpreted by some investigators to be of this type (e.g., Coughlan, 1981).

4.1.3 Secondary Allochthonous

Type # 5: beach and nearshore

Placer deposits of this type generally form on the beach face through a process of grain segregation during wave backwash; when subaerially exposed, they are often further enriched by aeolian reworking (Figure 6). The gold is fine-grained, often associated with black (heavy mineral) sands (which may themselves have some economic value) and concentrated in discrete lenticular bands. The source of sediment to the beach is a combination of offshore sediment, unconsolidated coastal bluffs and locally, fluvial discharge. They form principally in areas of sea level transgression with the exception of deltaic settings where they form during regressive phases.

The coastal beaches of northeast Graham Island, British Columbia were mined for gold and platinum and typify this deposit class (Samson, 1984). There is some indication that these beach placers are ephemeral and tend to be created and destroyed with great rapidity (e.g., seasonally or with large storms).

Type # 6; Offshore

As in the case of other allochthonous deposit types, offshore allochthonous placers contain fine-grained gold which is derived from a

secondary source and concentrated by means of differential entrainment. In the offshore zone, consistent replenishment and reworking of sediment are found in deltaic settings (Figure 7). Deltas are constructional features in which the sediment is derived from a point source (in contrast to a beach where there is a diffuse source) and is deposited more rapidly than it is eroded. In many deltaic settings the sediments aggrade very quickly and/or they are geomorphologically protected from high energy wave reworking (e.g., at fiord heads) thus impeding the formation of placer deposits.

No occurrences of deltaic gold deposits have been identified on glaciated shelves. However, on the Canadian shelf titanium sands off the north shore of Quebec have formed in a deltaic setting (Hein and Syvitski, 1988). Although this deposit does not contain particulate gold, the formation mechanism is similar to that envisioned for allochthonous gold placers and suggests under select conditions deltaic sediments may be a viable exploration target.

4.2 Relict

The following discussion will highlight the relict deposit types most likely to occur on high latitude shelves, some sedimentological controls on their development, and their preservation potential in the ocean.

type #7: relict fluvial

Submerged fluvial deposits may have formed prior to the most recent

phase of glacial inundation (i.e., pre-Late Wisconsin) either during interglacial stades or during the Tertiary. Two environments in which Tertiary fluvial deposits might survive glacial inundation are beneath a stagnant, non-erosive ice sheet (e.g., the Cariboo district in British Columbia; Boyle, 1979) or within valleys which trend perpendicular to the direction of ice flow and are thus are not fully scoured (e.g., the Chaudiere Valley district in Quebec; MacKay, 1921).

Relict fluvial deposits are best developed close to a primary source rock in seaward extensions of major river valleys. The most serious impediment to the offshore development of relict fluvial deposits is the unique, very localized and, in most instances, very unpredictable, zones of occurrence with respect to glacial dispersal. An additional problem is the large thicknesses of sediment, both glacial and postglacial, which infill incised channels on the shelf; current dredging techniques are generally limited to a combined water/sediment depth of less than 80m (Packer, 1987).

There are no known occurrences on of this deposit type on high latitude shelves. However, Hecate Strait (British Columbia) exhibits a high potential for this deposit type where evidence suggests that localized surficial exposures of channelized Tertiary bedrock may have never been glaciated (Barrie, per.comm.) and mineralized bedrock and placer gold deposits occur in the adjacent coastal zone (Samson, 1984).

type # 8: glacigenic sediment

Although glacigenic sediment is in general a poor exploration target for placer gold, it often acts as an intermediate collector which provides ample low grade material for subsequent postglacial reworking (e.g., deposit type #4). In unique instances, where they are located in proximity to a zone of rich primary gold mineralization, morainal and glaciofluvial sediments have been known to host economic placer gold (e.g., New Zealand; Henley and Adams, 1978). No offshore occurrences of relict glacigenic deposits have been recorded yet they remain a viable exploration target as glacial ice margins commonly extended beyond present coastal limits and the associated morainal and outwash sequences are now submerged on the shelf.

type # 9: relict beach and nearshore

Where prolonged periods of sea level stillstand occurred (e.g., during periods of glacial maximum) beach/nearshore placer deposits of type #1, 3 or 5 (Table 1) may have formed and in some instance, survived the subsequent sea level transgression. Deposit types #1 and #3 are associated with gravel sequences and would more readily survive a transgression than the sand facies of type #5. Where there was a very rapid rise in sea level and thus minimal sediment redistribution, type #5 may be found. Select gold placer occurrences offshore Alaska are interpreted to represent relict beach deposits of type #3 (Nelson and Hopkins, 1972). A titaniferous placer deposit in Queen Charlotte Sound, offshore British Columbia is interpreted to represent a relict beach/nearshore deposit of type #5 (Barrie and Emory-Moore, in prep.).

to the critical zone of sediment reworking.

It should be stressed that the models discussed are by no means exhaustive. The sedimentary models do not illustrate multiple reworking events, particularly with respect to pre-Late Wisconsin events and their possible role in placer formation. As with classical fluvial placers, where multiple rejuvenation and down-cutting events create increasingly rich deposits (Sutherland, 1985), multiple glaciations may have served to alternately concentrate and disperse placers of all types, creating locally enriched glacigenic deposits (e.g., Westland New Zealand; Henley and Adams, 1978). The classification scheme and sedimentary models do however provide a geologic framework and rationale for the assessment of relative marine placer potential; a recent study of gold placer potential on the Newfoundland shelf illustrates it's application (Emory-Moore and Solomon, submitted).

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Figure Captions

Figure 1: Deposit classification scheme illustrating the six modern and three relict deposit types and the factors which constrain their development. Representative examples of each deposit type are provided.

Figure 2: Legend for Figures 3 to 8.

Figure 3: Deposit Type #1: Primary Autochthonous Beach. Gold is eroded from a bedrock source and remains essentially in place, concentrated in beach gravels and bedrock crevices. Slow erosive transgression on a steep shelf provides optimal formation conditions.

Figure 4: Deposit Type #2: Primary Autochthonous Offshore. Submarine wave and current erosion of bedrock releases gold particles which are entrapped in gravel and bedrock interstices. Slow transgression on a shallow shelf maximizes the time and surface area exposed to erosive forces.

Figure 5: Deposit Type #3: Secondary Autochthonous Beach. Erosion of steep unconsolidated coastal bluffs during transgression results in concentration of gold in sand and gravel at the base of the bluffs.

Figure 6: Deposit Type #4: Secondary Autochthonous Offshore. Submarine reworking of auriferous glacial drift during transgression concentrates the gold in a surface lag. A shallow shelf permits maximization of surficial exposure.

Figure 7: Deposit Type #5: Secondary Allochthonous Beach/Nearshore. Gold in concentrated by wave action on beaches or at headlands by longshore drift.

Figure 8: Deposit Type #6: Secondary Allochthonous Offshore. Under appropriate hydraulic conditions, deltaic sediments are reworked and heavy minerals are concentrated; most likely by differential entrainment). The conditions will migrate as the delta progrades and distributary channels shift.

DEPOSIT CLASSIFICATION					CONSTRAINING FACTORS IN THE ASSESSMENT OF HIGH LATITUDE MODERN MARINE PLACERS														KNOWN OCCURENCES (see text for references)
					Sea Level					Wave Energy				Sediment Supply					
					Movement			Rate		Exposure		Shelf Gradient		Source Type				Net Accumulation	
					trans.	stable	regress	fast	slow	high	mod.	steep	shallow	bedrock	offshore	Coastal Bluffs	fluvial	high	low	
MODERN	Primary Source	beach/nearshore	Autochthonous	1																SHUTTLE ISLAND, B.C.
		offshore		2																COUNTRY HARBOUR, N.S.(?)
	Secondary Source	beach/nearshore	Autochthonous	3																OVENS, N.S.
		offshore		4																NORTON SOUND
		beach/nearshore	Allochthonous	5																GRAHAM ISLAND, B.C.
		offshore		6																SEPT ILES, QUEBEC
	CONSTRAINING FACTORS IN THE PRESERVATION POTENTIAL OF RELICT PLACER DEPOSITS																			
RELICT	fluvial			7																?
	glaciganic			8																WESTLAND NEW ZEALAND
	beach/nearshore			9																COOK BANK, B.C.

* where the source type is fluvial

FIGURE 1.

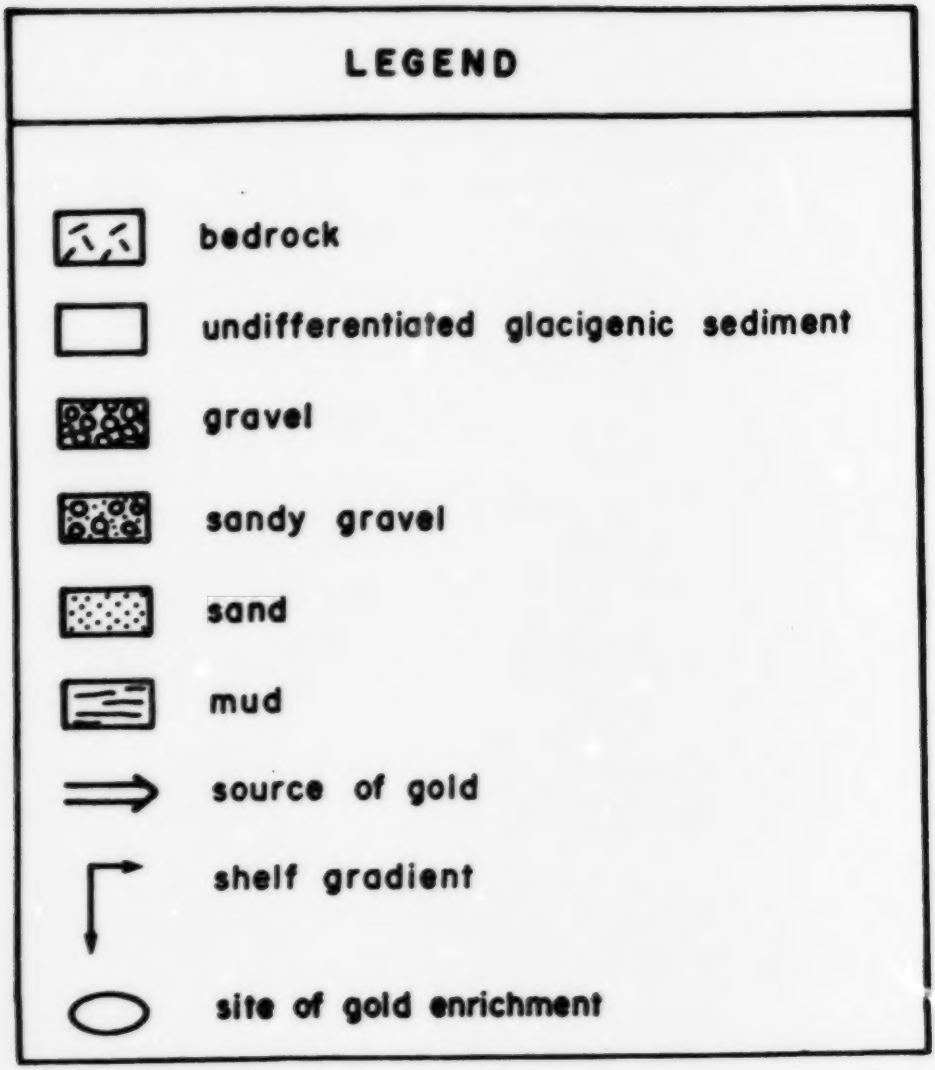
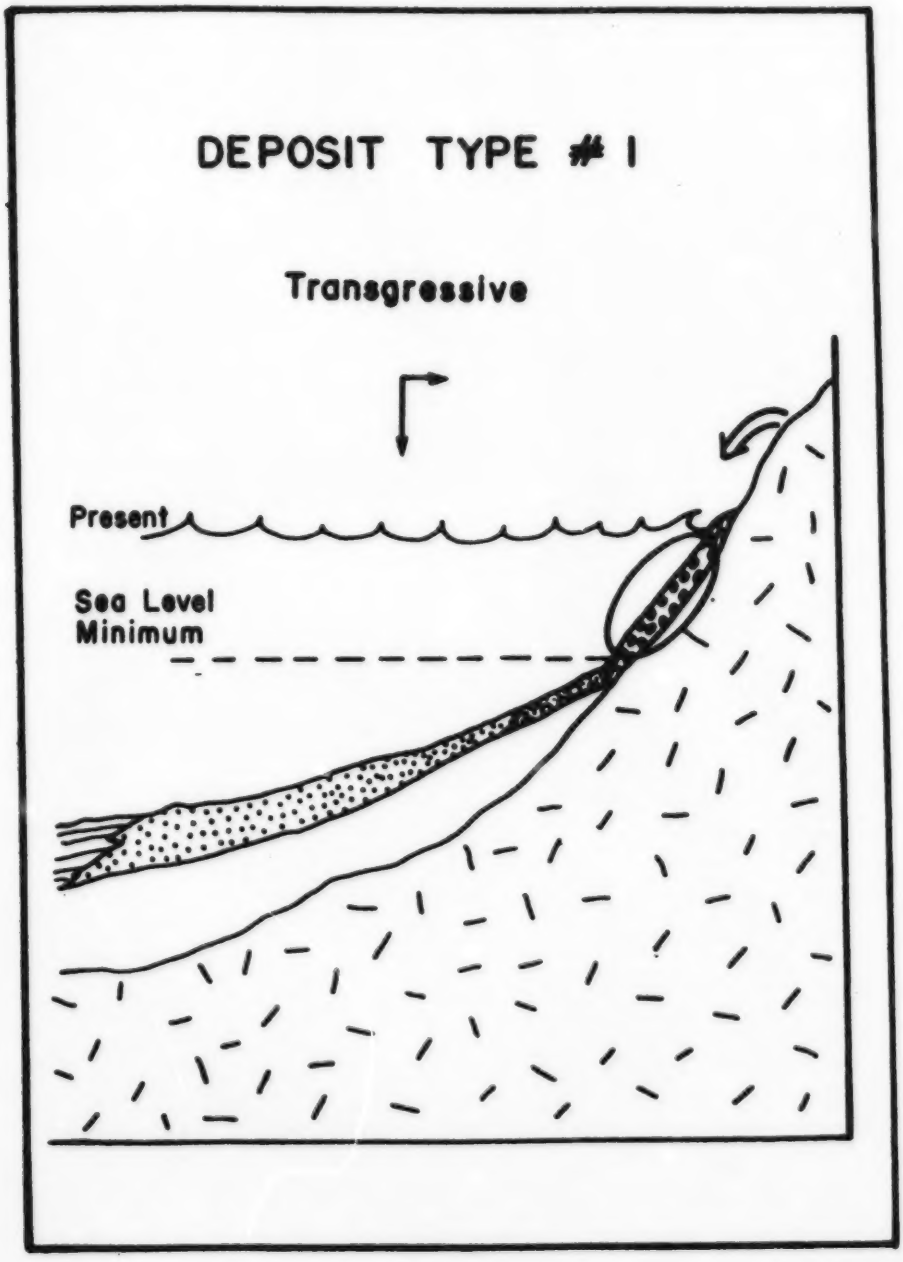

LEGEND
bedrock
undifferentiated glacigenic sediment
gravel
sandy gravel
sand
mud
source of gold
shelf gradient
site of gold enrichment

FIGURE 2.



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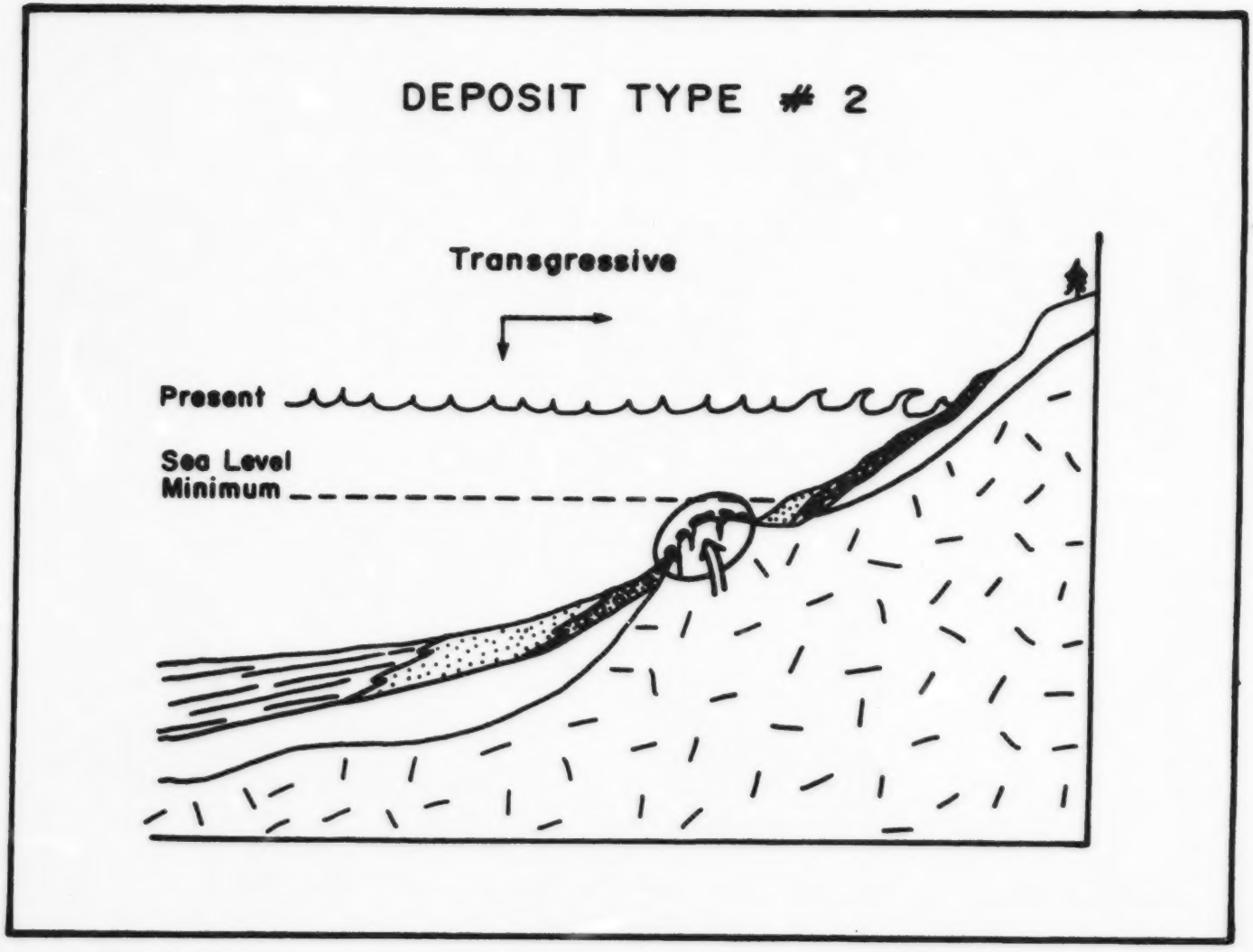

FIGURE 4.

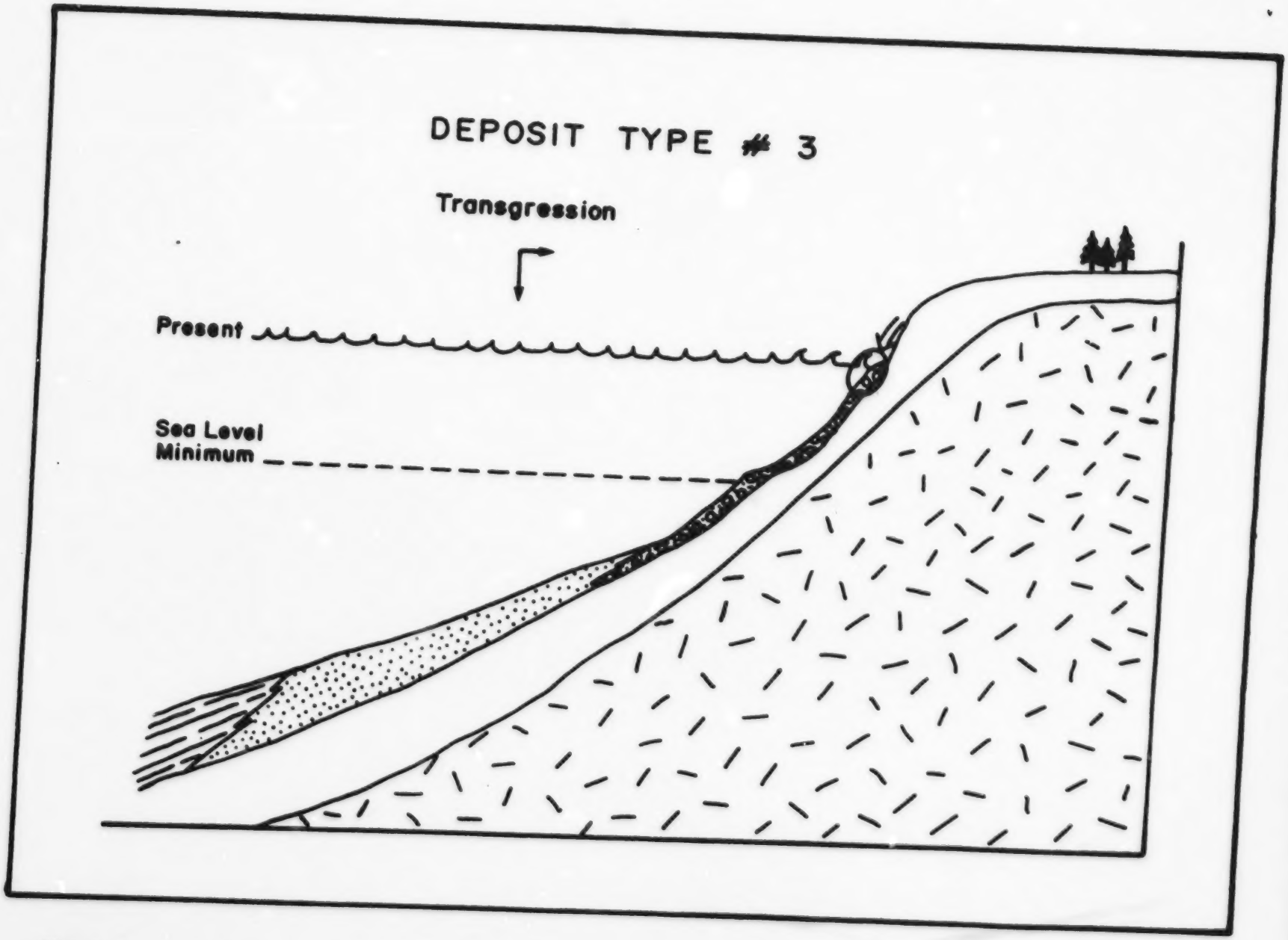

FIGURE 5.

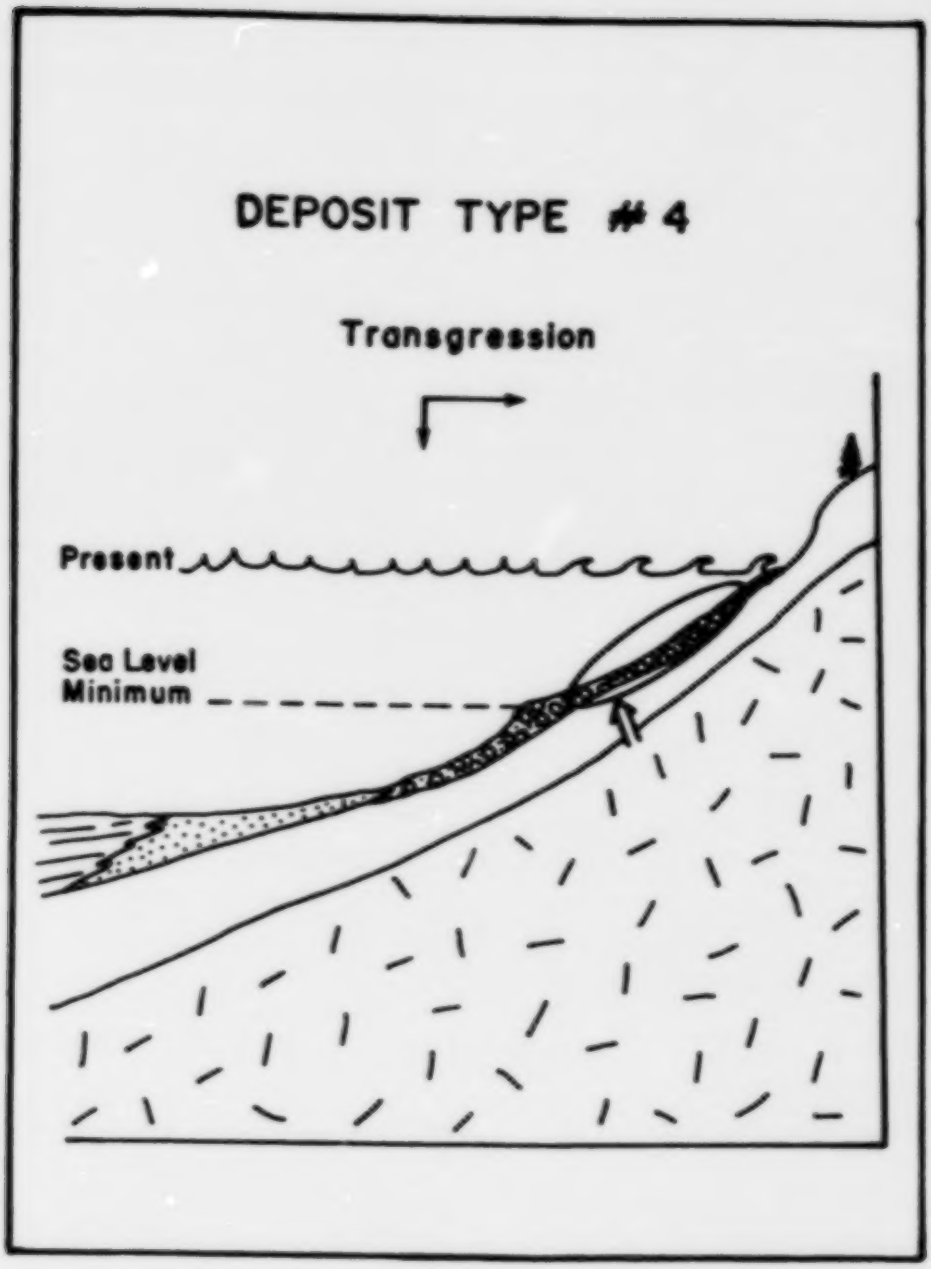

FIGURE 6.

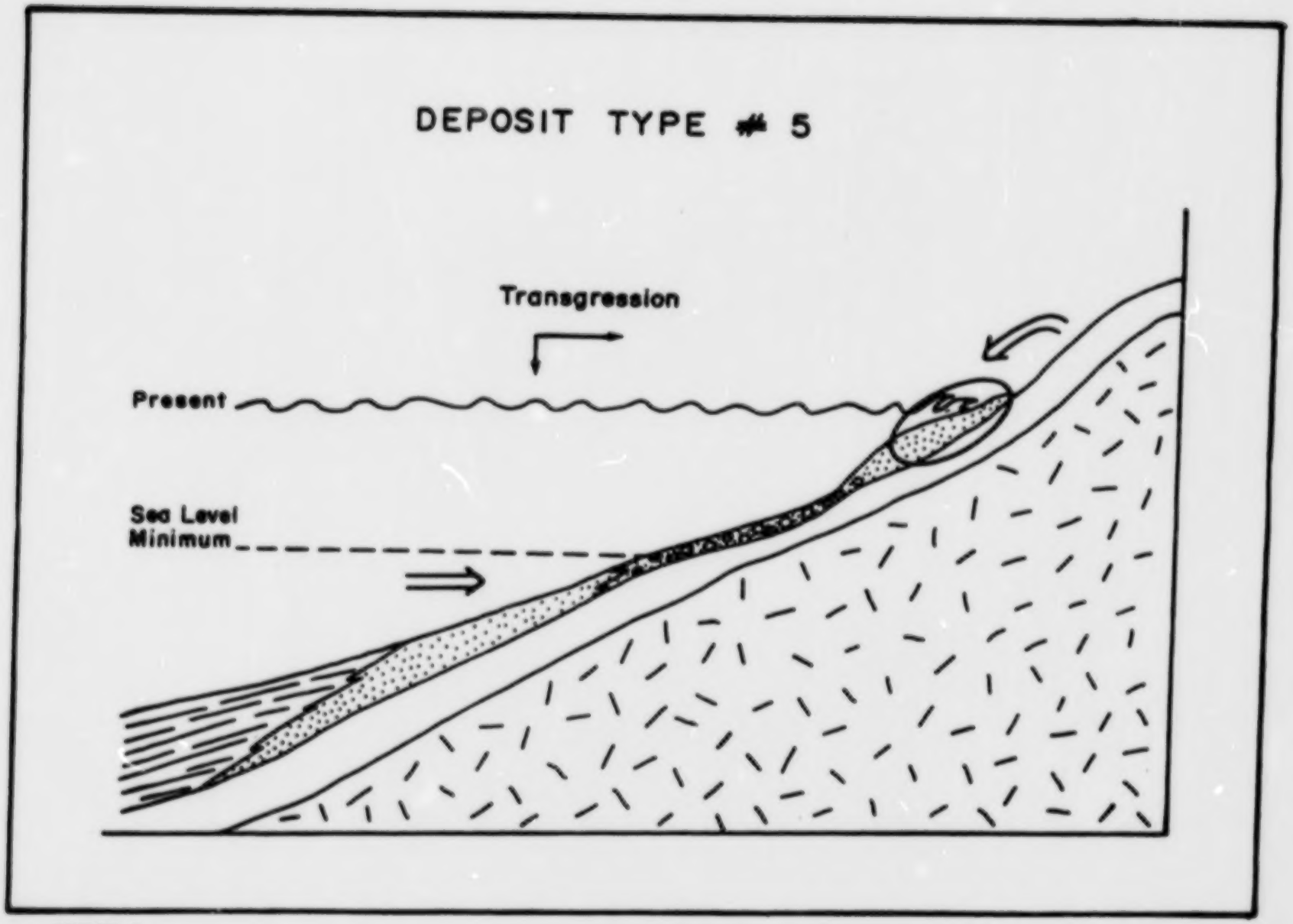

FIGURE 7.

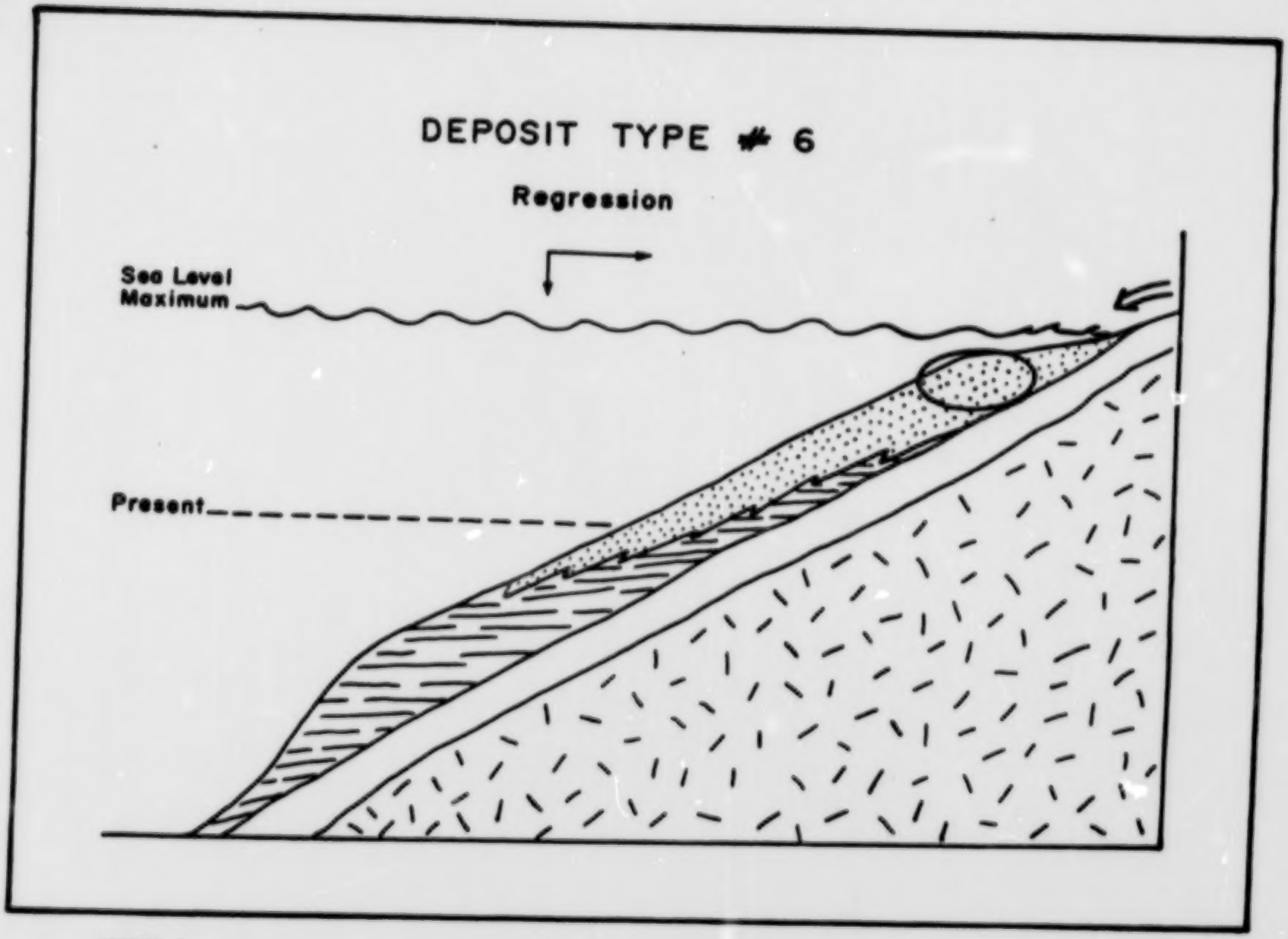

FIGURE 8.